Remote Sensing of Cloud Properties with the Research Scanning Polarimeter (RSP)

Bastiaan van Diedenhoven^{1,2}, Brian Cairns², Mikhail Alexandrov^{1,2}, Andrzej Wasilewski³, Matteo Ottaviani⁴

1: Columbia University, 2: NASA GISS, 3: Trinnovim, 4: Steven Institute of Technology

bastiaan.vandiedenhoven@nasa.gov





Overview

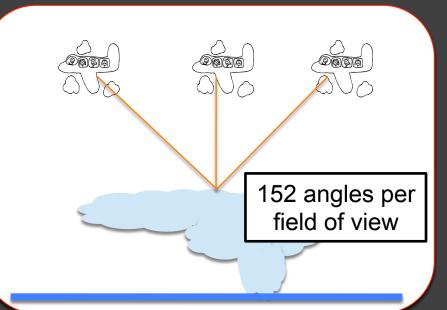
- RSP instrument
- RSP cloud products
- RSP ice cloud retrieval examples and statistics



Airborne Research Scanning Polarimeter (RSP)

- Prototype for APS on Glory
- Two versions built 1999 & 2001
- I, Q & U in 9 bands in visible and shortwave infrared:
 - 410, 470, 555, 670, 864, 960, 1593, 1880, 2263 nm
 - 1880 nm for cirrus (lower atmosphere screened by water vapor absorption)
- 152 viewing angles per scene + dark reference and calibrator views on every scan
- 14 mrad Field of view (~200m on ground, ~50m on ice clouds)
- Accuracy: polarimetric <0.5%, radiometric <5%





RSP cloud products

Clouds

Hyper –stereo cloud top height

Polarimetry (Rayleigh) cloud top height

Optical thickness

Thermodynamic phase (liquid or ice)

Liquid clouds

Effective size (SWIR)

Effective size (Polarimetry)

Size distribution shape

Super-cooled liquid detection

Ice clouds

Ice crystal effective size

Crystal aspect ratio and roughness/distortion

Ice crystal asymmetry parameter

Oriented ice detection

RSP cloud products

Clouds

Hyper –stereo cloud top height

Polarimetry (Rayleigh) cloud top height

Optical thickness

Thermodynamic phase (liquid or ice)

Liquid clouds

See poster by Mikhail
Alexandrov:
"Retrievals of Liquid
Cloud Properties from the
Research Scanning
Polarimeter Measurements
Made during the SEAC4RS
Field Experiment"

Ice clouds

Ice crystal effective size

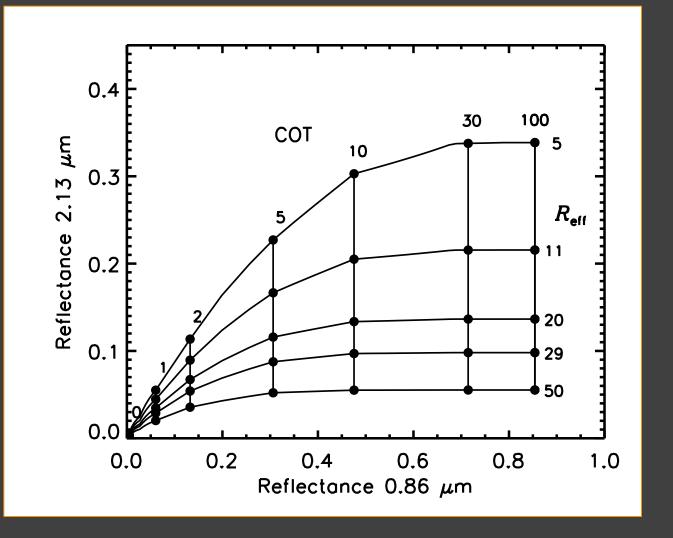
Crystal aspect ratio and roughness/distortion

Ice crystal asymmetry parameter

Oriented ice detection

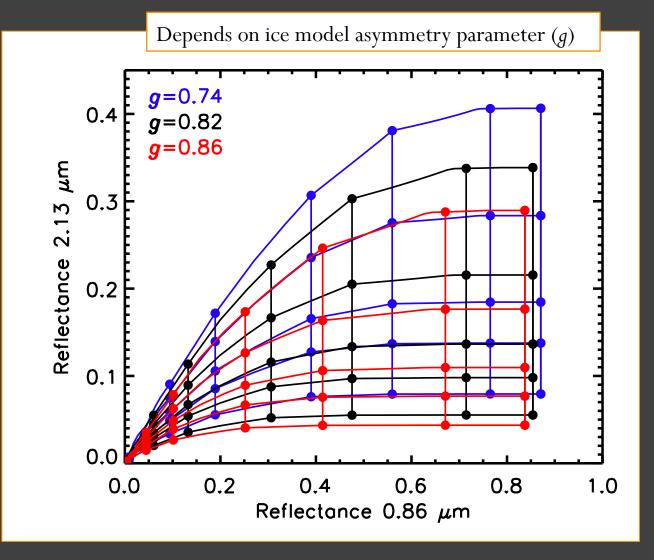
Cloud optical thickness and effective radius retrievals

- Nakajima-King retrievals
 - Non- absorbing band (0.865μm)
 - Absorbing band (1.59, 2.25μm)

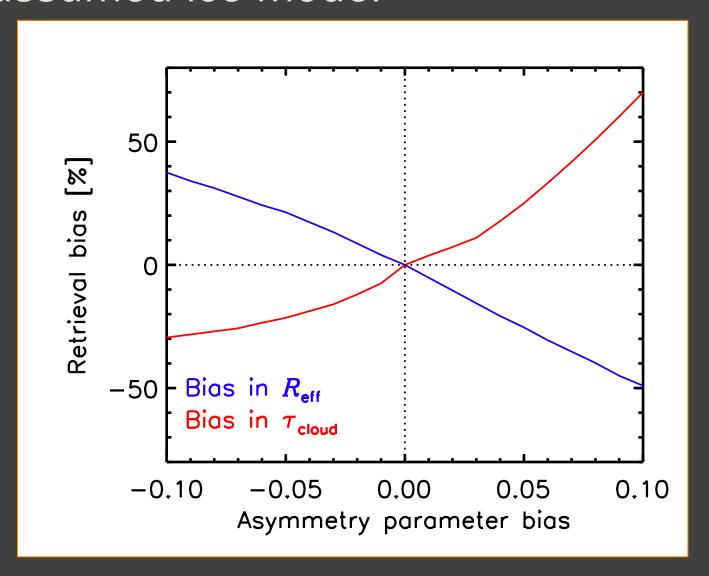


Cloud optical thickness and effective radius retrievals

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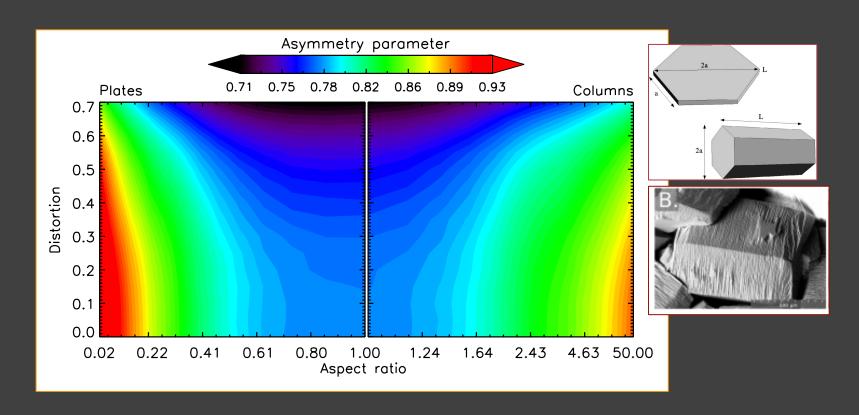


COT and R_{eff} retrievals depend on g of assumed ice model

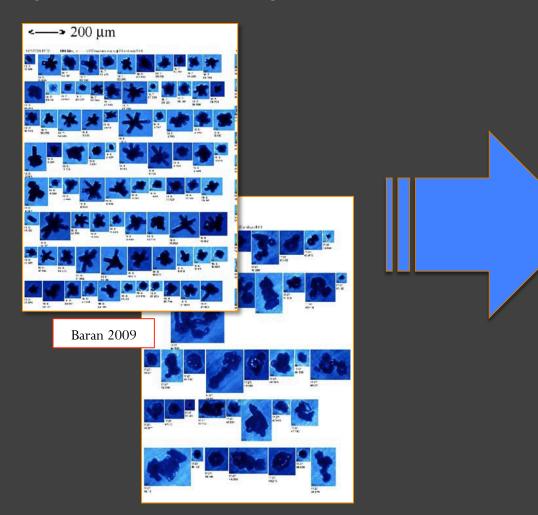


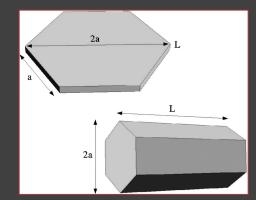
Ice crystal asymmetry parameter

- Ice crystal asymmetry parameter mainly depends on
 - Shape (aspect ratio)
 - Distortion/microscopical roughness/impurity



Using single hexagonal columns and plates with varying aspect ratio and distortion as radiative proxies of complex ice







Crystal shape from Polarization

Polarization contains info about

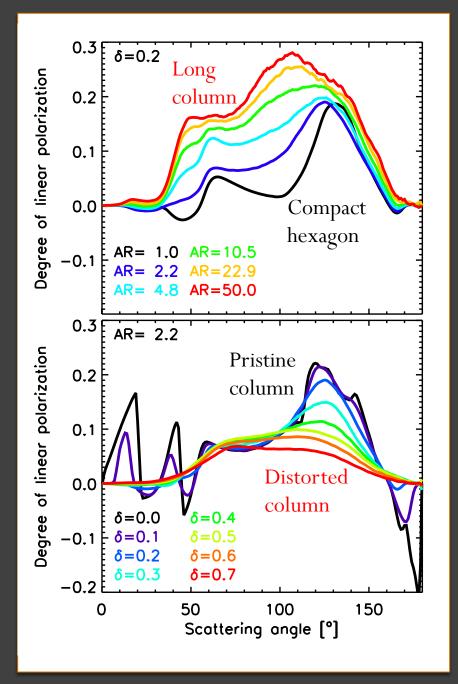
- Aspect ratio (AR)
- Distortion δ (Macke et al. 1996)

Multi-directional polarized reflectance measurements

conserve

Single scattering features

Retrieve aspect ratio and distortion to estimate asymmetry parameter for the use in R_{eff} and COT retrievals



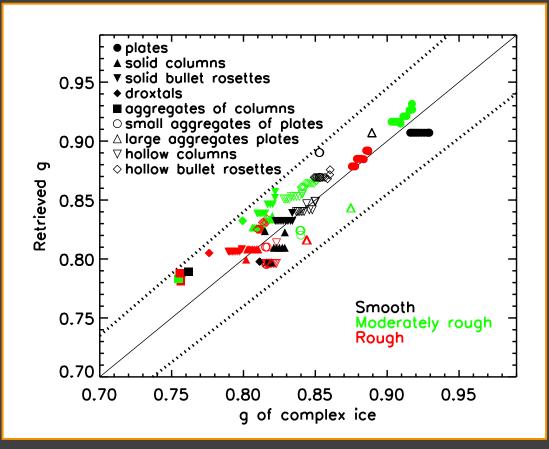
Simulated data test

Simulated data:

- Complex ice habits (Yang et al.)
- 3 roughness degrees
- 20 different size distributions

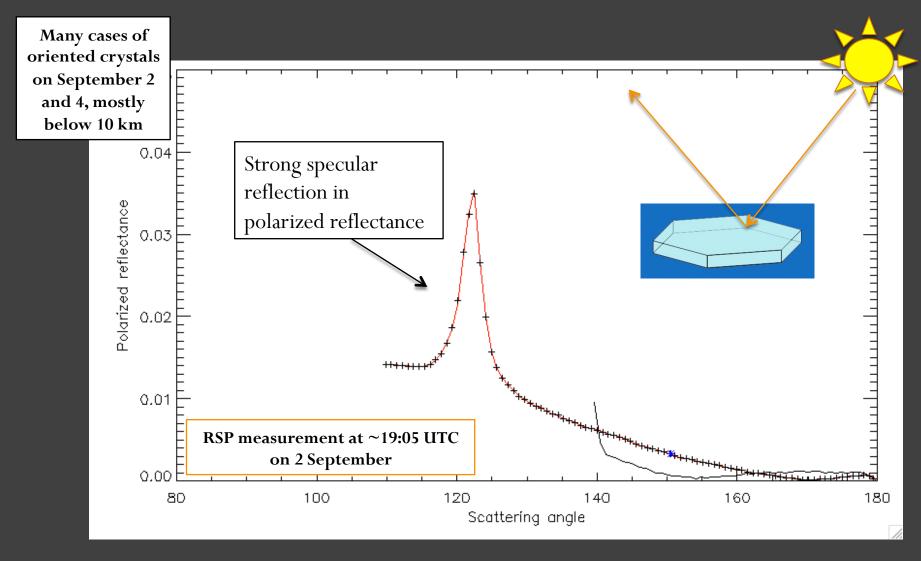
Retrieved asymmetry parameter

- Within 5% (0.04)
- Mean bias: 0.004
- Standard deviation: 0.02



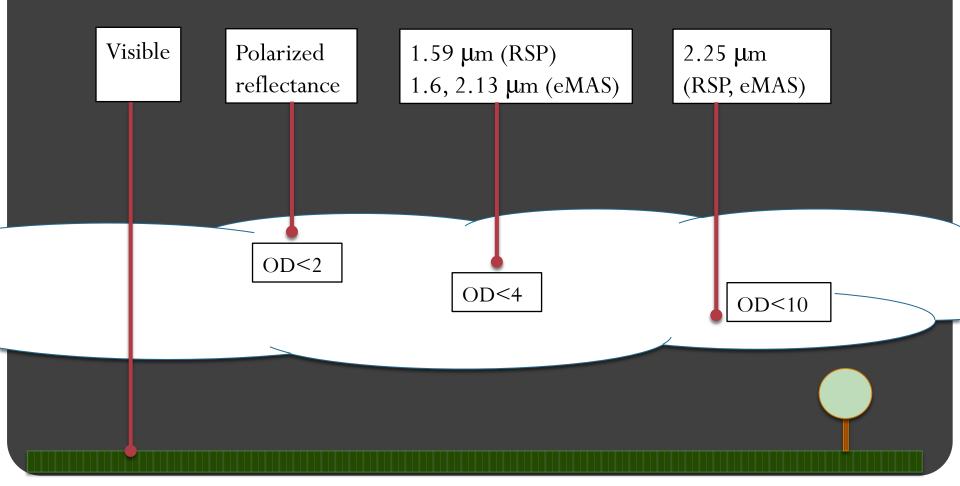
van Diedenhoven et al., Atmos. Meas. Tech., 2012; Atmos. Chem. Phys., 2013

Oriented ice detection



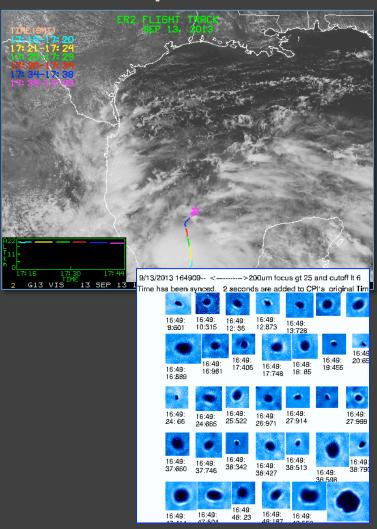
Cloud top sampling

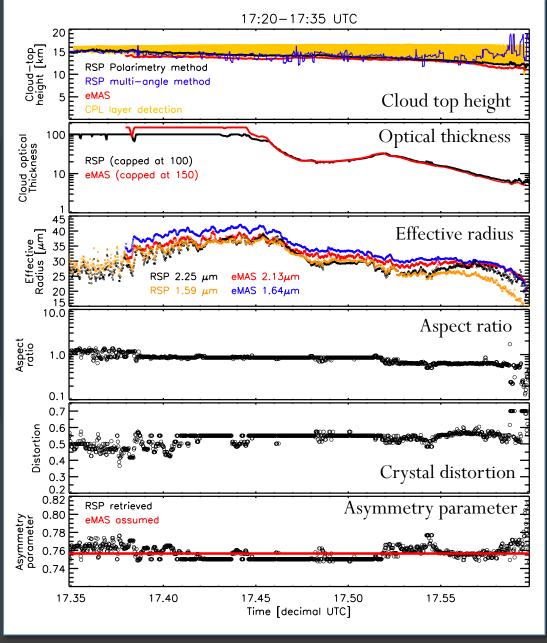


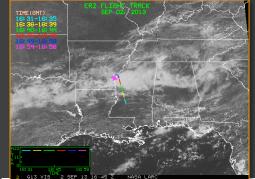


PREMIMINARY

Tropical storm
Ingrid
13 September

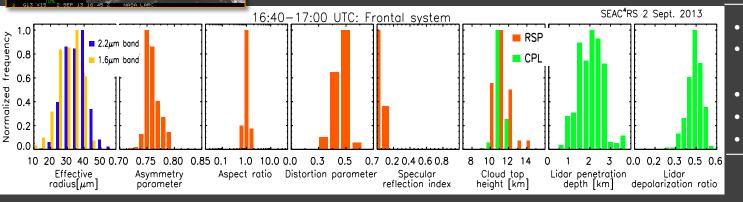






Variation on 2 Sept.

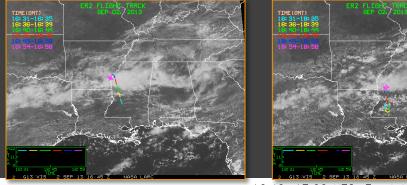
Restricted to COT>5



- CTH ~ 11 km
- Distorted compact crystals
- $R_{\rm eff} \sim 30-40 \ \mu {\rm m}$
- $g \sim 0.75$
- Extended tops

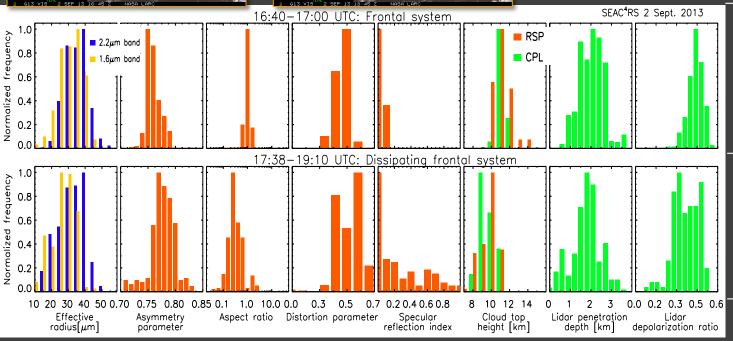
RSP

Cloud physics lidar

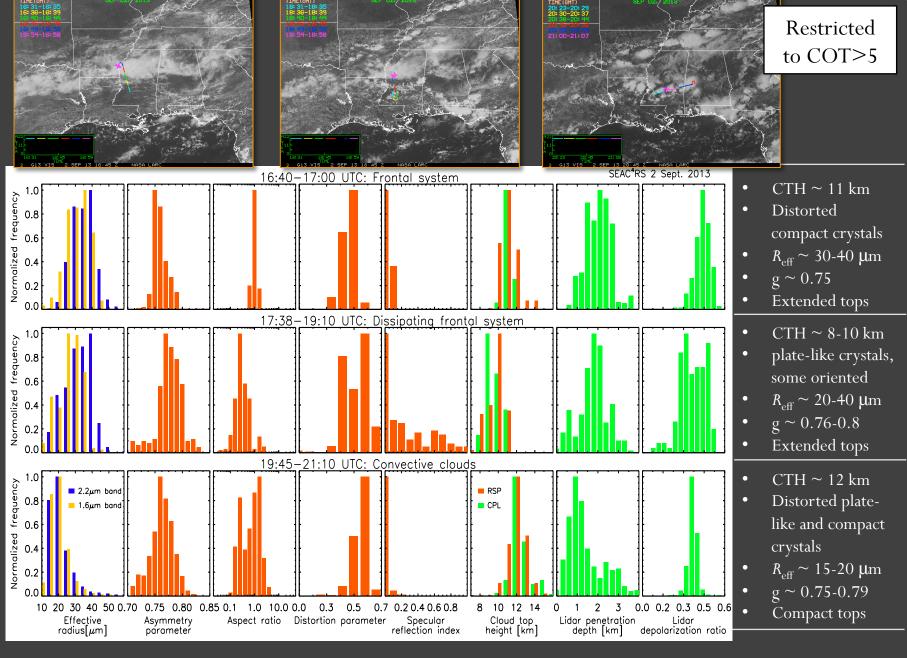


Variation on 2 Sept.

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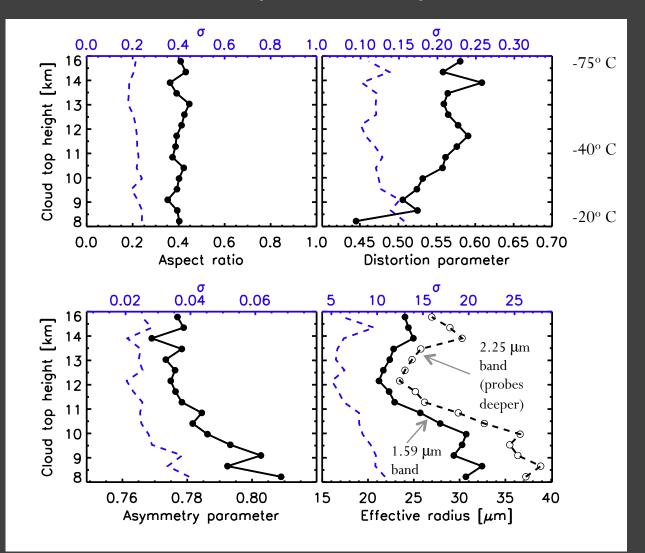


- CTH ~ 11 km
- Distorted compact crystals
 - $R_{\rm eff} \sim 30\text{-}40 \ \mu \mathrm{m}$
- $g \sim 0.75$
- Extended tops
 - $CTH \sim 8-10 \text{ km}$
- plate-like crystals, some oriented
- $R_{\rm eff} \sim 20-40 \ \mu {\rm m}$
- $g \sim 0.76 0.8$
- Extended tops



SEAC⁴RS statistics (COT>5)

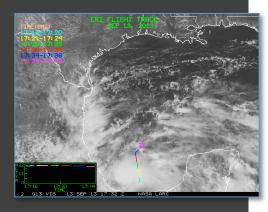
- 8/21, 8/30,
 9/2, 9/04,
 9/11, 9/13,
 9/16, 9/18,
 9/22
- Excluding TS Ingrid
- Mean values (black) and standard deviations (blue)

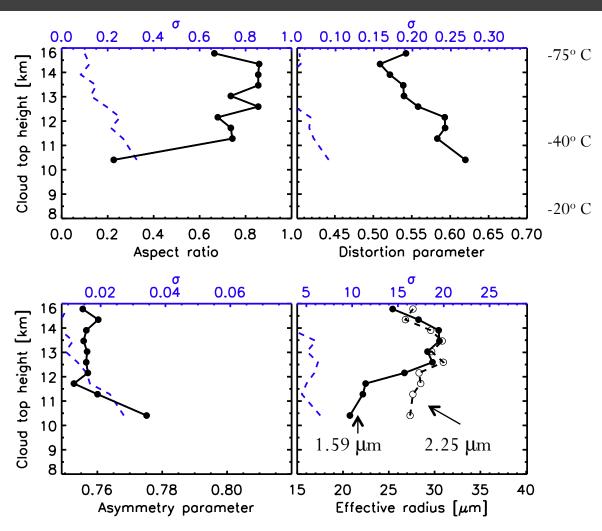




SEAC⁴RS statistics (COT>5)

Tropical StormIngrid 9/13

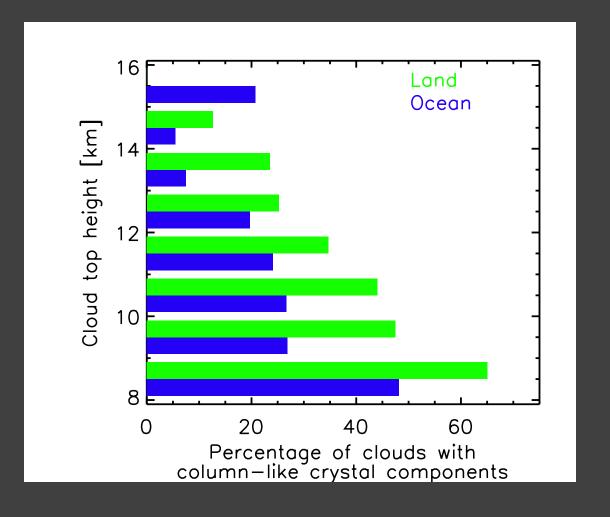






SEAC⁴RS statistics (COT>5)

- Mostly plate-like particle components
- Above land,
 column-like
 crystals increasingly
 occur with
 decreasing height



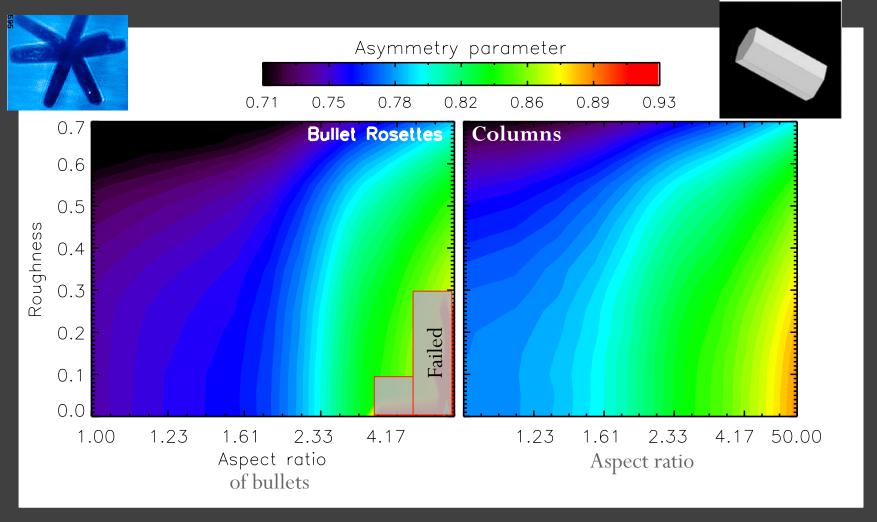
Future plans

- Include COT<5</p>
- Correct level-1 data for change in flexing of ER-2 wings during flights (Just completed)
- Evaluate calibration and retrievals using eMAS, CPL, APR-2, AirMSPI, in situ, etc.
- Document and analyze variation of cloud top properties with e.g., cloud type and atmospheric state



Back up

Complex vs simple ice crystals



• Phase matrix $\mathbf{P}_{\text{complex}} \approx \mathbf{P}_{\text{components}}$ (Fu 2007; Um & McFarquhar 2007; 2009)

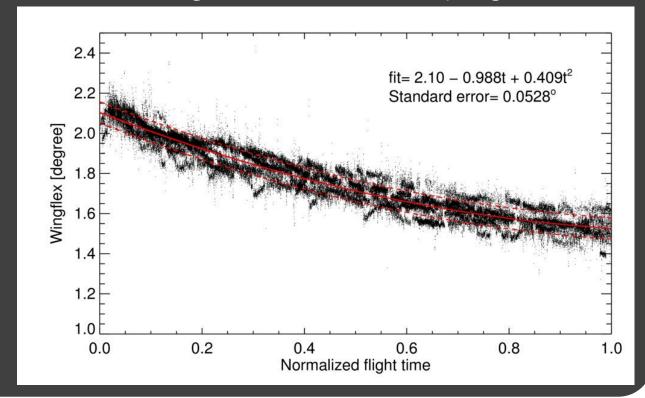
ER-2 Wingflex



- Wingflex assumed to be indicated by different in roll measured by ER-2 body INS and eMAS (wing) INS
- Wingflex assumed to be the same in both wings

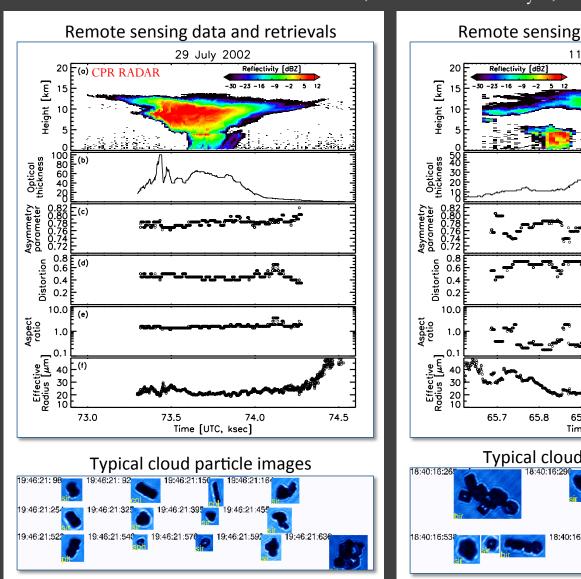
• Parameterized as function of flight time normalized by flight

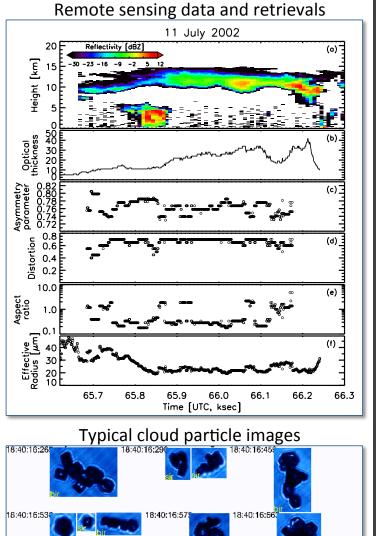
duration



Application to RSP at CRYSTAL-FACE

van Diedenhoven et al., Atmos. Chem. Phys., 13, 3185-3203, 2013

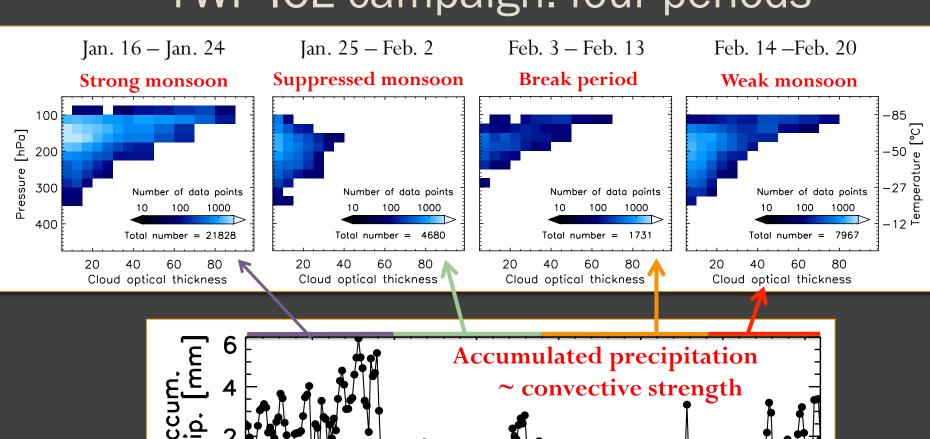


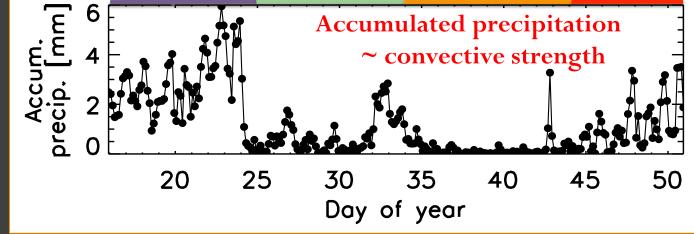


Van Diedenhoven et al., in preparation
See also van Diedenhoven et al.,
JAS, 2012

POLDER+MODIS

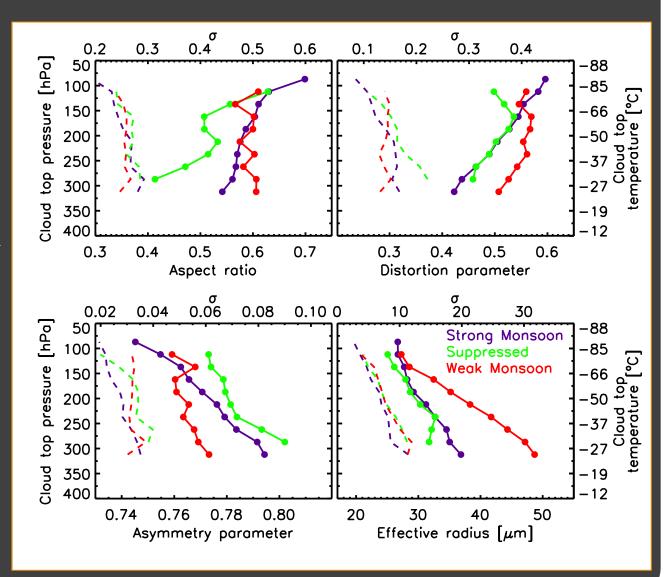
TWP-ICE campaign: four periods





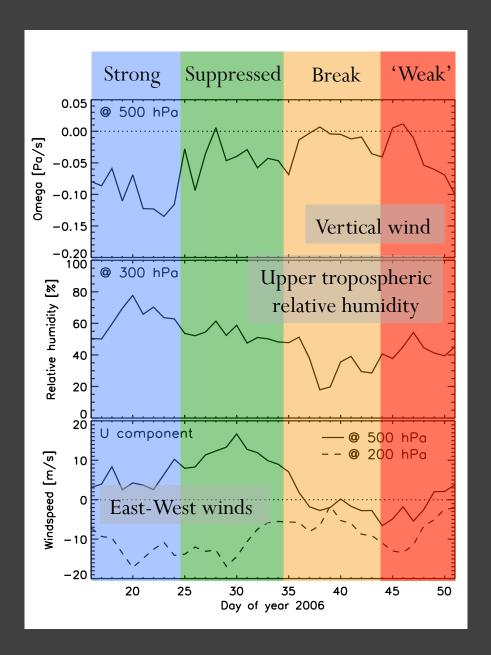
- Mean (solid) & standard deviations (dashed)
- With decreasing height
 - AR and distortion decrease
 - g increases
 - \bullet $R_{\rm eff}$ increases
- Vertical variation depends on atmospheric conditions

POLDER+MODIS: TWP-ICE



TWP-ICE NCEP reanalysis Atmospheric state

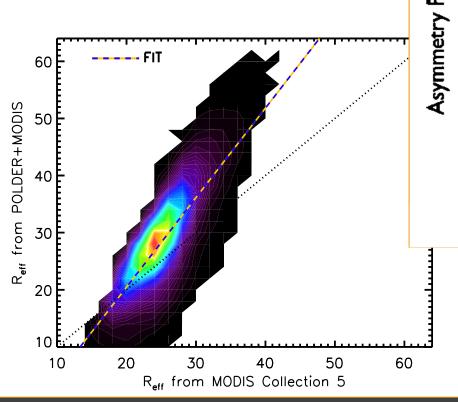
'Weak' monsoon has weaker upper tropospheric wind shear

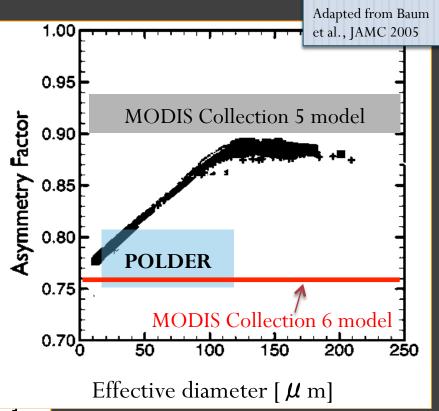


Van Diedenhoven et al., in preparation

TWP-ICE: MODIS Collection 5 R_{eff} strongly biased

- MODIS collection 5
 - R_{eff} generally underestimated
 - R_{eff} range underestimated

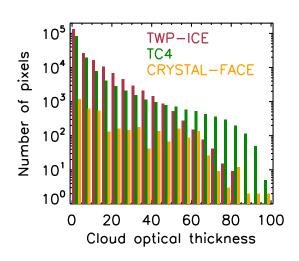


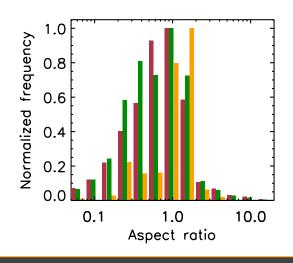


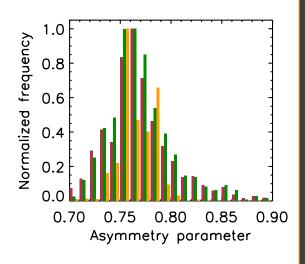
PDFs for over convective clouds

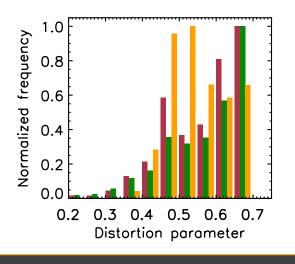
Campaigns:

- TWP-ICE
 - NorthAustralia
 - POLDER
- TC4
 - Costa-Rica
 - POLDER
- CRYSTAL-FACE
 - South Florida
 - airborne RSP
 - Limited cloud sampling



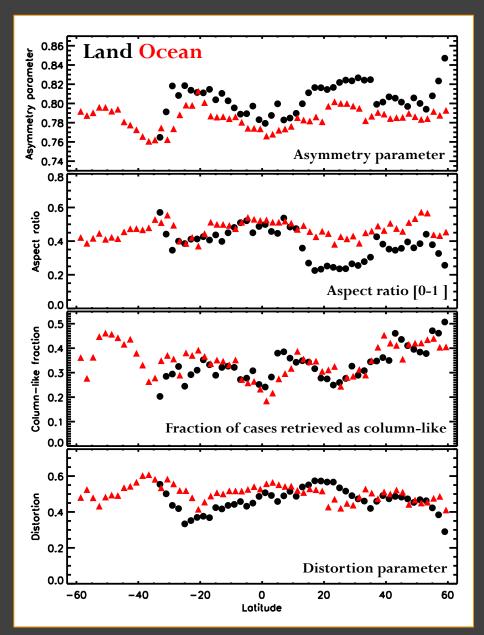






Preliminary POLDER global results

- Only COT>5
- 3 days in January, 3 days in June
 - Tropics: $g \sim 0.76 0.8$
 - mid-latitudes: $g \sim 0.76$ -0.8
 - $10-30^{\circ}$: $g \sim 0.78-0.83$
 - $g \sim 0.02$ greater over land
 - Low aspect ratios North of 15°
 - Mostly plate-like
 - Highly distorted $\delta \sim 0.5$

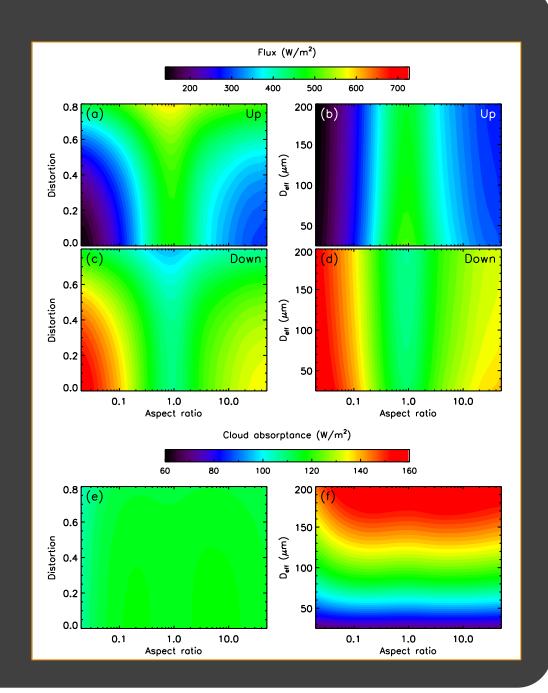


Solar Flux variations from varying size and shape

- Optical thickness = 4
- $SZA = 60^{\circ}$

van Diedenhoven et al., "A flexible parameterization for shortwave optical properties of ice crystals", JAS, in press

http://www.columbia.edu/~bv2154/parameterization.html



Solar Flux variations from varying size and shape

- Optical thickness = 2
- $SZA = 60^{\circ}$

van Diedenhoven et al., "A flexible parameterization for shortwave optical properties of ice crystals", JAS, in press

http://www.columbia.edu/~bv2154/parameterization.html

